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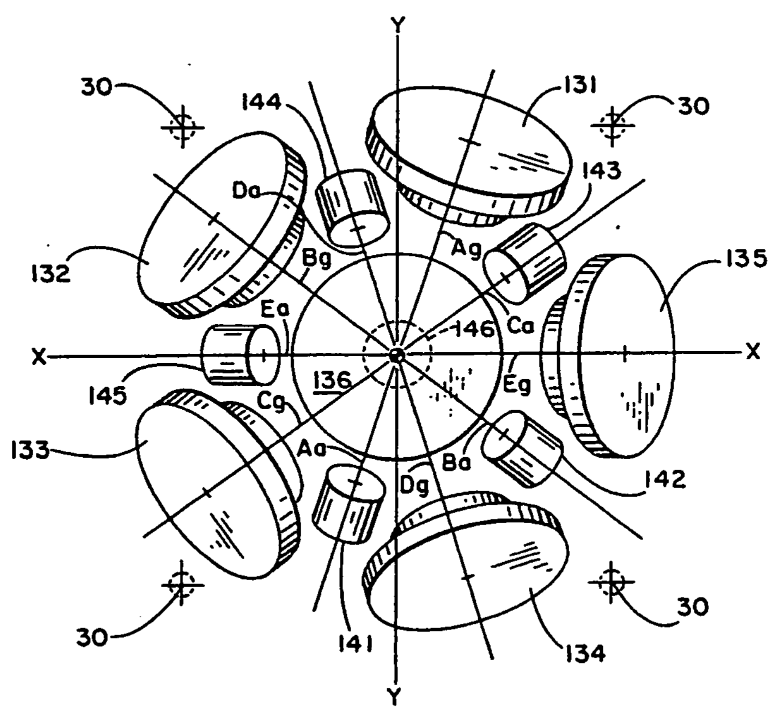
(54) Title: SKEWED AXIS INERTIAL SENSOR ASSEMBLY



(57) Abstract

Six gyros (131-136) and six accelerometers (141-146) are mounted to faces of a single sensor base member (10). The sensors are arranged such that their input axes all pass through a common centerpoint (CCP) and that the common centerpoint (CCP) is the center of gravity of the total assembly.

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SKEWED AXIS INERTIAL SENSOR ASSEMBLY

Background of the Invention

Field of the Invention

This invention pertains to a skewed axis inertial sensor assembly, to a gyro and accelerometer mounting base for a skewed axis inertial sensor assembly, and to a method of providing inertial reference.

Background of the Invention

Use of redundant strapdown inertial reference units (herein after referred to as an "IRU") in both commercial aviation and space applications is well known in the art. Redundancy concepts are intended to achieve significant improvement in reliability, and thus enhance mission success. Generally, a redundant strapdown inertial navigation system utilizes two or three discrete inertial reference units. Each IRU includes a discrete inertial sensor apparatus (hereinafter referred to as "ISA") for producing sensor data, and associated electronics for signal processing and generating inertial reference data. ISA's generally include three discrete gyros and three

discrete accelerometers for the production of necessary sensor data required by the IRU. All three gyros and all three accelerometers and their electronics must be operative in an ISA, as described, for each IRU of a redundant IRU system to produce complete inertial reference data.

A three IRU redundant strapdown system just described requires in combination a total of nine gyros and nine accelerometers. This 3 IRU type of system is a "fail op/fe gyroscopes may be on the same side of the suspension plane provided that a counter balancing mass is made part of the base member 10 to cause the common centerpoint CCP to be the center of gravity.

Although preferably the base member is intended to be a unitary structure, it is also within the spirit and scope of the present invention that the base member may be a plurality of piece parts which have been fixed or bonded together to form a single structure, and that the sensor mountings are such that the input axis of the sensors meet the intended conditions.

optimal data processing with self contained failure isolation for up to two out of six of either sensor module type, and continued operations with as many as three out of six failures of each sensor module type.

The art of ring laser gyros has matured over recent years to yield excellent performing gyros. However, as is well known, ring laser gyros have a need for a mechanical dither for rotationally oscillating the gyro such that the gyro avoids the so called lock-in condition. It is further understood by those skilled in the art, that an IRU which mounts three gyros in an orthogonal configuration results in the input axes of these gyros to move in a cone shape due to cross coupling of the mechanical dither from one gyro to the other two gyros. It is therefore desirable to provide an inertial sensory assembly that reduces cross coupling between ring laser gyros.

Object of the Invention

It is an object of this invention to provide a method of providing a redundant inertial reference with a single base member for mounting inertial measuring sensors.

It is an object of this invention to provide a method of providing inertial reference with skewed axis sensor assembly having dynamic stability.

It is object of this invention to provide a an improved sensor mounting base for mounting a plurality of mechanically oscillated dithered ring laser gyros.

It is an object of this invention to provide a single sensor module comprised of a single base member for mounting a plurality of accelerometers and a plurality of mechanically dithered ring laser gyros in which the base member is constructed to provide enhanced dynamic stability.

It is an object of this invention to provide a single sensor module comprised of a single base member for mounting six accelerometers and six gyros in which the sensors are oriented to provide the equivalent of four discrete redundant strapdown inertial reference units.

Summary of the Invention

In the present invention, the inertial sensor assembly includes six gyros and the six accelerometers mounted to faces of a single sensor base member, preferably composed of a single unitary body. The six gyros are arranged with their respective input axis being mutually exclusive from another and passing through a common centerpoint, and six accelerometers are arranged with their respective input axis being

mutually exclusive from another and also passing through the same common centerpoint at which the gyro input axes converge. The input axes of the six gyros and six accelerometers are at the same time arranged to define six discrete rotation reference axes and six discrete acceleration reference axes so as to provide sufficient sensor data for subsequent signal processing to provide the equivalent of four redundant inertial reference units.

In one embodiment of the invention, the sensor base member is provided with a plurality of suspension members for mounting the base member to a chassis. The base member is coupled to the chassis through a plurality of elastic members which have elastic centerpoints which define a suspension plane. The base member, suspension members, and elastic members are arranged such that the suspension plane extends through the common centerpoint defined by the input axes of the gyros and the accelerometers, and in which the common centerpoint is preferably the center of gravity of the total suspended assembly.

A method of providing multiple skewed axis inertial reference has the steps of mounting six gyros and six accelerometers one each in six discrete axes on a single base member.

Brief Description of the Drawings

FIG. 1 is a top plan view of an inertial sensor assembly base member in accordance with the present invention.

FIG. 2 is a projected elevational view taken from lines 2-2 of FIG. 1.

FIG. 3 is an elevational sectional view through lines 3-3 of FIG. 1.

FIG. 4 is a projected bottom plan view taken from lines 4-4 of FIG. 2.

FIG. 5 is a detail view of a suspension mount of Figure 1.

FIG. 6 is a top plan view schematic of the sensor geometry of the ISA of FIG. 1.

FIG. 7 is an elevational plan schematic of the sensor geometry of the ISA of FIG. 6 taken from lines 3-3 of FIG. 1.

FIG. 8 is a top view of Figure 1 with gyro sensors attached.

Details of the Specification

As particularly illustrated in Figures 1-8, the inertial sensor assembly in accordance with the present invention includes a base member 10 for providing mounting surfaces for six gyros and six accelerometers (shown on subsequent drawings). Figure

1 shows a top plan view of base member 10. Base member 10 is shown to be symmetrical about the X-axis, and more particularly about the X-Z plane (the Z-axis being out of the plane of the paper). The base member 10 is preferably comprised of a block of a selected material, generally to provide high stiffness and light weight, for example Aluminum. Base member 10 includes an upper portion 12a and a lower portion 12b as defined by an imaginary suspension plane SP in parallel with the X-Y plane and passing through the common centerpoint CCP as will be subsequently described.

GYRO MOUNTING

The base member portion 12a includes five gyro mountings apertures 31-35 in the form of a ring around the Z-axis. The mounting apertures are constructed in body member 10 such that when the gyros are mounted, the extension of each input axis of each gyro passes through the common centerpoint CCP. Further, the angle is the same between the Z-reference-axis and the gyro. Lastly, the angle between the input axes of adjacent gyros are equal. In the preferred embodiment the spherical angle between the input axis of any one of gyros 31-35, and the Z-axis and the spherical angle between adjacent

gyro input axes is 63.4 degrees - the spherical angle between normals to faces of a dodecahedron. Base member upper portion 12a also includes a sixth gyro mounting aperture 36 for mounting a sixth gyro such that its input axis is parallel with the Z-reference-axis and also passes through CCP. Thus the six gyros have an equal spherical angle between each other.

ACCELEROMETER MOUNTING

Lower portion 12b of base member 10, on the opposite side of the suspension plane SP as the gyro mountings, provides a plurality of mounting apertures 41-45 for six accelerometers. It is well understood by those skilled in the art of inertial sensor assemblies that the accelerometer input axis should preferably be as close to the center of gravity or center of mass of the base member. In practice of the present invention, accelerometers are generally of smaller size than gyros (although not always). In this situation, the base member lower portion 12b is structurally smaller and allows closer proximity of the accelerometers to the common centerpoint CCP. The structural details are particularly illustrated in Figure 2 which shows a projected elevational view of

Figure 1 taken from lines 2-2, Figure 3 which is an elevational view through lines 3-3, and Figure 4 which is a bottom plan view taken from lines 4-4.

Specifically, the lower portion 12b includes five accelerometer mounting apertures 41-45 in the form of a ring around the Z-axis. The mounting apertures 41-45 are constructed in base member 10 such that when the accelerometers (not shown) are mounted, the extension of the input axis of each accelerometer passes through the common centerpoint CCP. Further, the angle between the accelerometer input axis and the Z-axis of each accelerometer is the same. Lastly, the angle spherical between the input axes of adjacent accelerometers are equal. In the preferred embodiment the spherical angle between the input axis of any one of accelerometers 41-45 and the Z-axis, and the spherical angle between the input axes of adjacent accelerometers is 63.4 degrees - the spherical angle between normals to faces of a dodecahedron. Lower portion 12b also includes a sixth accelerometer mounting aperture 46 for mounting a sixth accelerometer such that its input axis is aligned with the Z-reference-axis and also passes through CCP. Thus the six accelerometers have an equal spherical angle between each other.

The arrangement of mounting apertures for the gyros and accelerometers on base member 10 is such that the X-Z plane of symmetry is maintained. Further, each of the gyros has its input axis co-linear with one accelerometer input axis, with the sensor pair being on opposite sides of the suspension plane SP. Thus, six inertial reference axes are established. In the preferred embodiment of the invention, the six inertial reference axes are the six axes of a regular dodecahedron - each axis being the normal to two opposite faces of a regular dodecahedron. Thus, all sensor input axes are at a spherical angle of 63.4 degrees (one place accuracy) from each other.

SUSPENSION MOUNTS

Suspension mounts 26 for the sensor assembly are particularly illustrated in Figure 1-8. Details of only one of four suspension mount assemblies 200 is illustrated in the Figures, the others not shown are configured in a similar manner. Sensor base member 10 is shown having four suspension mounts 26. The centerline 27 of each mount is in parallel with the Z-reference axis and is equidistant from the common centerpoint CCP. An elastic suspension member 28, well known in the art, is assembled between each

suspension mount 26 and to chassis mounts 11. The elastic suspension member 28 and the suspension mount 26 are secured together by, for example a bolt 801 shown in Figure 8. Each elastic suspension member 28 includes, for example, a member 802 for being secured to chassis 11, thereby suspending the base member 10 through the elastic suspension member 28.

Each suspension mount 26 has a suspension face 29 against a respective elastic suspension member 28. The suspension mounts 26, by virtue of the suspension faces 29, define a flat mounting plane MP. Each of the suspension members 28 has an elastic centerpoint 30. The elastic centerpoint 30 of all of the suspension members 28 are equidistant from the common centerpoint CCP. The elastic centerpoints 30 are intended to jointly define a flat suspension plane SP which extends through the common centerpoint CCP. The mounting plane MP is preferably parallel to and spaced from the suspension plane SP. X-Y coordinate axes nominally lie in the suspension plane SP, and the X-Z plane is perpendicular to the suspension plane SP. The suspension mounts 26 are also intended to be symmetrical about the X-axis and X-Z plane. As illustrated in figure 2, the suspension mounts 26 are located on the same side, lower portion 12b of body member 10, as the accelerometer mounting apertures 41-46.

In accordance with one aspect of the present invention, it is intended that the common centerpoint CCP be the same as the center of mass or center of gravity for the suspension mass comprised of the combination of the base member 10, and all of the gyros and accelerometers as mounted to base member 10, and the suspension mount assemblies. In other words, the common centerpoint of all the reference axes of the sensors is the same as the center of gravity of the system, and that the suspension plane SP passes through the center of gravity as well as the common centerpoint CCP of the reference axis.

SENSOR GEOMETRIC STRUCTURE

Referring to Figure 6, six discrete gyros 131-136 are intended to be mounted in mounting apertures 31-36 respectively, and six discrete accelerometers 141-146 are intended to be mounted in accelerometer mounting apertures 41-46. As aforesaid, all of the input axes of each of the sensors passes through the common centerpoint CCP. Gyros 131-136 have input axes which correspond to axes Ag, Bg, Cg, Dg, Eg and Zg respectively. Similarly, accelerometers 141-146 have input axes corresponding to Aa, Ba, Ca, Da, Ea and Za respectively. Input axes Ag and Aa, Bg and Ba, Cg and Ca, Dg and Da, Eg and Ea, and Zg and Za all being co-linear.

In the preferred embodiment of the invention, the base member 10 is constructed as aforesaid and illustrated herein such that six sensor pairs are established such that a sensor pair has one discrete accelerometer directly opposite the common centerpoint CCP from a respective gyro, and the input axes of the sensor-pair being co-linear. A portion of the geometric sensor structure of Figure 6 is shown in Figure 7 to show the sensor pair alignment. Each paired accelerometer input axis and gyro input axis lie upon and define a straight reference axis. Specifically, sensor axis Zg, Za are in reference axis ZZ, sensor axis Ag, Aa are in reference axis AA, sensor axis Bg, Ba are in reference axis BB, sensor axis Cg, Ca are in reference axis CC, sensor axis Dg, Da are in reference axis DD, sensor axis Eg, Ea are in reference axis EE. The six discrete reference axes ZZ, AA, BB, CC, DD, EE all converge upon the common centerpoint CCP and are skewed with respect to each other.

Figure 8 illustrates base member 10 with gyros attached thereto. It also illustrates the four suspension mounts.

It should be understood by those skilled in the art, that the structure as defined relative to figures 1-7 may be constructed in a manner different

than that shown in the drawings. The drawings generally illustrate a base member composed of a sphere like block in which twelve planar surfaces are created thereon. Both the upper and lower portions of the base member include a first one of the planar surfaces being parallel to the X-Y plane, and the remaining five planar surfaces forming a cone-shape with the first planar surface being at the apex of the cone. Apertures are then formed through these planar surfaces in order to provide a cavity for mounting gyros and accelerometers therein as close to the common centerpoint as possible. The size of the mounting apertures depends upon the configuration of gyro or accelerometer sensor selected. Thus, a unitary base member structure has been described which provides mounting for six gyros and six accelerometers in a specific configuration which allows for a set of six reference axis in which each reference axis has a sensor pair comprised of one accelerometer and one gyro having there respective input axis being co-linear with each other. The planar surfaces on the block are geometrically configured such that normals to all of the surfaces can intersect at a common centerpoint.

Although the base member mounting apertures in the block have been shown, all that is required is

a mounting surface or means to secure the sensors to the base member. The base member having the apertures was utilized to achieve good dynamic stability by advantageous application of inertial moment considerations. Of course, variations in sensor configurations will effect the base member structure with out departing from the true spirit and scope of the present invention.

It should be obvious to those skilled in the art that there are many possible variations of the described structural configuration in order to accomplish the intended requirements and functions as already described herein.

In the embodiments of the invention as illustrated, further apertures 332 and 333 were made into the base member 10 beneath the location of the mounting apertures 32 and 33. Adjustment of these apertures provides a method for positioning the center of gravity to be at the common centerpoint CCP. Although other balancing structures are of course possible, the balancing apertures in the body were intended to be symmetrical again about the X-axis for maintaining planar symmetry about the X-Z plane.

Depending upon the material selected for the base member 10 and the case materials for either the gyros or the accelerometers, variations in the

structure are of course within the scope of the present invention. Specifically, it was found that with an aluminum base member and a steel casing for an accelerometer, it was preferable to have the accelerometer held up away from the base member by pedestals 300 as illustrated in the Figures.

The present invention is particularly suited for application of ring laser gyros in which the ring laser gyro includes a mechanical dither mechanism which oscillates the gyro relative to the case. Generally, when a triad of ring laser gyros are orthogonally mounted to a platform, the input axis tends to rotate in a conical pattern. This is attributed to cross coupling between the mechanical dithering mechanisms and the platform. In practice of the present invention with mechanically dithered ring laser gyros, by virtue of all the reference axis pointing to the common centerpoint, and the common centerpoint being at the center of mass, and that the suspension plane passes through the center of mass results in excellent dynamic stability such that the problem of cross coupling as described is virtually eliminated.

Although the base member has been illustrated in a system requiring six gyros and six accelerometers, the base member may be modified, and

within the spirit and scope of the present invention, to accommodate any plurality of gyros and accelerometers in which the input axis of the sensors meet at a common centerpoint and/or the common centerpoint is at the center of gravity. Specifically, the principles of the present invention are applicable to a triad of gyros and accelerometers.

Further, it is also within the spirit and scope of the present invention that the accelerometers and the gyroscopes may be on the same side of the suspension plane provided that a counter balancing mass is made part of the base member 10 to cause the common centerpoint CCP to be the center of gravity.

Although preferably the base member is intended to be a unitary structure, it is also within the spirit and scope of the present invention that the base member may be a plurality of piece parts which have been fixed or bonded together to form a single structure, and that the sensor mountings are such that the input axis of the sensors meet the intended conditions.

THE CLAIMS

The embodiments of an invention in which an exclusive property or right is claimed are defined as follows:

1. An inertial sensor apparatus comprising:
   a sensor mounting base member;
   a plurality of discrete gyros affixed to said base member and arranged with their respective input axes being mutually exclusive from one another and passing through a common centerpoint;
   a plurality of discrete accelerometers affixed to said base member and arranged with their respective input axes being mutually exclusive from one another and passing through said common centerpoint; and
   the suspension mass comprised of said base member, said accelerometers, and said gyros is configured such that there exists at least one plane of symmetry passing through said suspension mass.

2. The apparatus of claim 1 further comprising a plurality of suspension members for coupling said base

member to a platform, each of said suspension members having an elastic centerpoint, and said elastic centerpoints defining a suspension plane extending through said common centerpoint.

3. The apparatus of claim 2 wherein said common centerpoint is the center of gravity of said suspension mass including said suspension members.

4. The apparatus of claim 2 wherein said common centerpoint is within the periphery of said base member.

5. The apparatus of claim 2 wherein said elastic centerpoints of said suspension members are equidistant from said common centerpoint.

6. The apparatus of claim 2 having four said suspension members, with four said respective elastic centerpoints, said four suspension members and said four respective elastic centerpoints being symmetrical about said plane of symmetry.

7. The apparatus of claim 1 wherein said common centerpoint of is the center of gravity of said suspension mass.

8. The apparatus of claim 1 wherein said common centerpoint is within the periphery of said base member.

9. The apparatus of claim 1 in which the base member, said gyros, and said accelerometers jointly comprise a single suspended mass having an inertial center at said common centerpoint.

10. The apparatus of claim 1 wherein said base member includes means in said base member which is geometrically symmetrical about said plane of symmetry for causing the center of gravity of said suspended mass to be at said common centerpoint.

11. The apparatus of claim 1 wherein said gyros and said accelerometers are on opposite sides of a first plane which is orthogonal to said plane of symmetry and passing through said common centerpoint.

12. The apparatus of claim 11 wherein the input axis of one of said gyros and the input axis of one of said accelerometers are co-linear and define a common central reference axis which is perpendicular to said first plane.

13. The apparatus of claim 12 in which the input axis of five of said plurality of gyros and the input axis of five of said plurality of accelerometers separately define a ring about said central reference axis.

14. The apparatus of claim 12 wherein said central gyro is closer to said common centerpoint than said remaining plurality of gyros, and said central accelerometer is closer to said common centerpoint than said remaining plurality accelerometers.

15. An inertial sensor apparatus comprising:

a sensor mounting base member;

six discrete gyros affixed to said base member and arranged with their respective input axes being mutually exclusive from one another and passing through a common centerpoint within the periphery of said base member;

six discrete accelerometers affixed to said base member and arranged with their respective input axes being mutually exclusive to one another and passing through said common centerpoint; and

the suspension mass comprised of said base member, said discrete accelerometers, and said discrete gyros is configured such that there exists at least one plane of symmetry passing through said suspension mass, and in which each gyro input axis is co-linear with only one accelerometer input axis.

16. The apparatus of claim 15 in which each gyro input axis is equiangularly separated from the input axis of an adjacent gyro, and in which each accelerometer input axis is equiangularly separated from the input axis of an adjacent accelerometer.

17. The apparatus of claim 15 in which the input axes of all accelerometers and said gyros are arranged to correspond to the array of normals to the faces of a dodecahedron such that all input axes are at the same spherical angle from each other.

18. The apparatus of claim 15 further comprising a plurality of suspension members for coupling said base member to a platform, each of said suspension members having an elastic centerpoint, and said elastic centerpoints defining a suspension plane extending through said common centerpoint.

19. The apparatus of claim 18 having four said suspension members, with four said respective elastic centerpoints, said four suspension members and said four respective elastic centerpoints being symmetrical about said plane of symmetry.

20. The apparatus of claim 15 wherein said gyros are ring laser gyros.

21. A sensor mounting base member for a skewed axis redundant strapdown inertial sensor apparatus comprising:

a block having twelve non-coplanar mounting means on a periphery of said block surrounding a common centerpoint for separately mounting one of six gyros and six accelerometers on each one of said mounting means, said mounting means being arranged such that said six gyros and said six accelerometers have input axes which all pass thorugh said common centerpoint; and

a plurality of suspension mounts on said block in which said suspension mounts are equidistant from said common centerpoint.

22. The apparatus of claim 21 wherein said input axis of each of said sensors is aligned with a selected one of the normals to the planar surfaces of a dodecahedron.

23. The apparatus of claim 21 wherein said block, said gyros, and said accelerometers define a single suspended mass having at least one plane of symmetry.

24. The apparatus of claim 23 wherein said gyros and said accelerometers are on opposite sides of a first plane passing though said common centerpoint and orthogonal to said plane of symmetry.

25. The apparatus of claim 24 wherein the input axis of a central one of said gyros and a central one of said accelerometers is perpendicular to said first plane.

26. The apparatus of claim 25 wherein said central gyro is closer to said common centerpoint than said remaining ones of said gyros, and said central accelerometer is closer to said common centerpoint than said remaining ones of said accelerometers.

27. The apparatus of claim 21 wherein said gyros are ring laser gyros.

28. An inertial sensor apparatus comprising:

a body;

a plurality of gyros and a plurality of accelerometers mounted on said body such that the input axis of each of the gyros and said accelerometers pass through a common centerpoint; and

the suspension mass including said body, said gyros, and said accelerometers being such that the center of mass thereof is the same as said common centerpoint, and the position of said gyros and said accelerometers on said body is such that there exists at least one plane of symmetry which passes through said suspension mass.

29. The apparatus of claim 28 wherein there exists a suspension plane which passes through said common centerpoint, and in which all of said gyros are on one side of said suspension plane, and all of said accelerometers are on the opposite side of said suspension plane.

30. The apparatus of claim 28 wherein said body includes elastic suspension mounts for coupling said body to a platform, said elastic suspension mounts having elastic centerpoints which are on a suspension plane which passes through said common centerpoint.

31. The apparatus of claim 28 in which there are at least six gyros and six accelerometers.

32. The apparatus of claim 28 in which there are at least three gyros and three accelerometers.

33. The apparatus of claim 30 where there are only four elastic suspension mounts and said elastic suspension mounts conform with said plane of symmetry.

34. The apparatus of claim 30 wherein said gyros are ring laser gyros.

35. The method of providing a multiple skewed axis inertial reference system comprising;

mounting on a body six gyros and six accelerometers in which the input axis of each of said gyros and said accelerometers pass thorugh a common centerpoint suspending said gyros, said

accelerometers, and said body such that a suspension plane passes through said common centerpoint, and said common centerpoint being the center of gravity of a suspension mass including said body, said accelerometers and said gyros; and

suspending said body on elastic suspension mounts having elastic centerpoints which lie in said suspension plane.

36. The method of claim 35 further comprising the step of mounting said gyros and said accelerometers so as to define six reference axes in which there exists only one gyro and one accelerometer having an input axis along one of said reference axes.

37. The method of claim 35 including the further step of mounting said gyros equiangularly divergent to each other, and mounting said accelerometers equiangularly divergent to each other.

38. The method of claim 35 comprising the step of arranging said suspension mass to conforms with a plane of symmetry through said suspension mass.

39. The method of claim 38 comprising a step of suspending said body, said gyros and said accelerometers such that the plane of suspension passes through said common centerpoint and said common centerpoint is the center of gravity of said suspension mass.

40. The method of claim 35 further comprising a step of mounting of said accelerometers closer to said common centerpoint than said gyros.

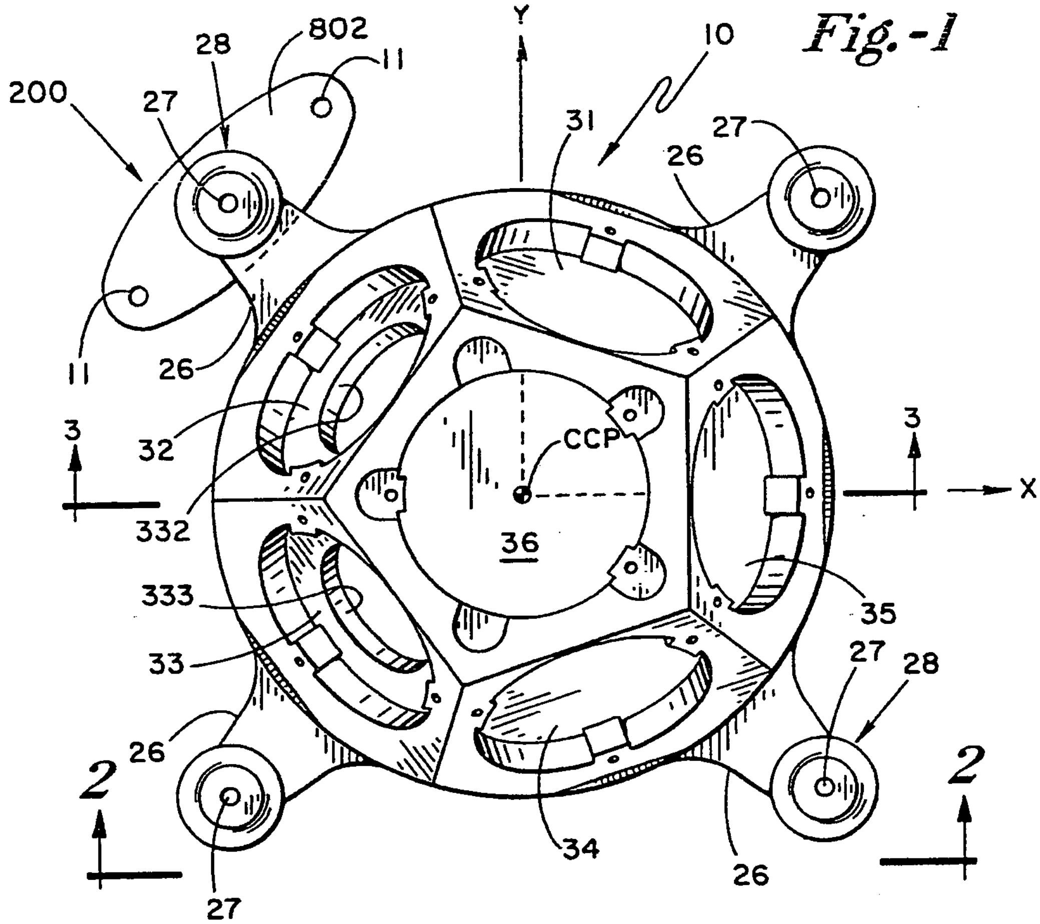

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Fig.-1

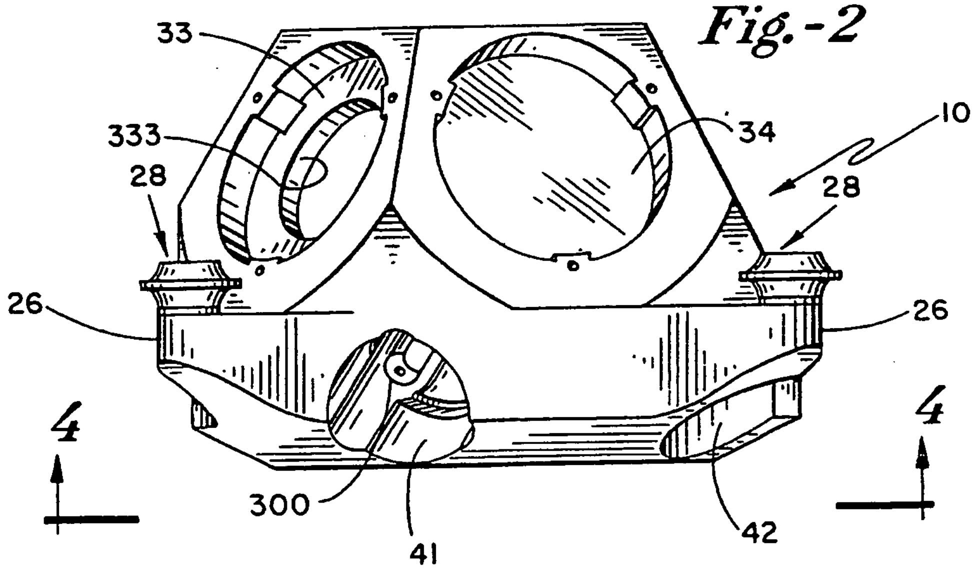

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Fig.-2

Fig.-3

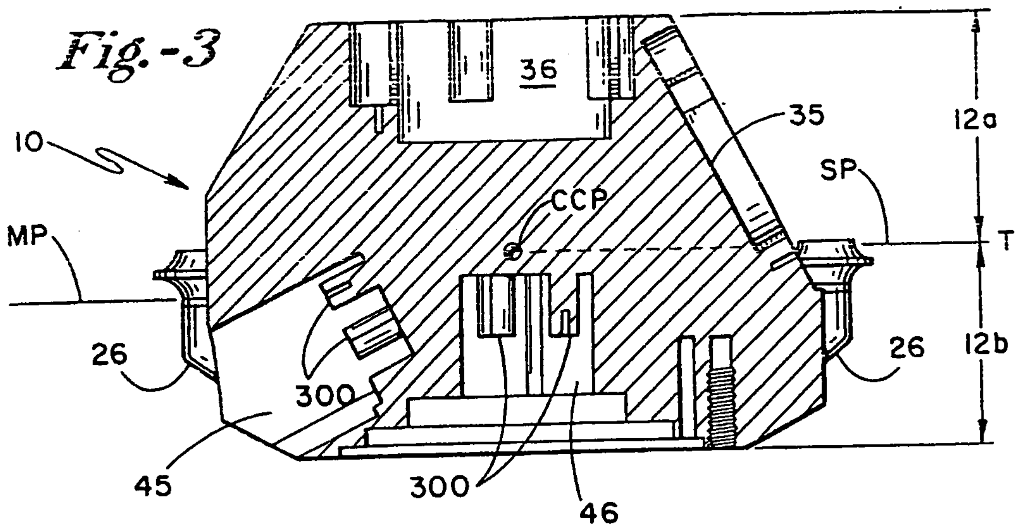

Fig.-4

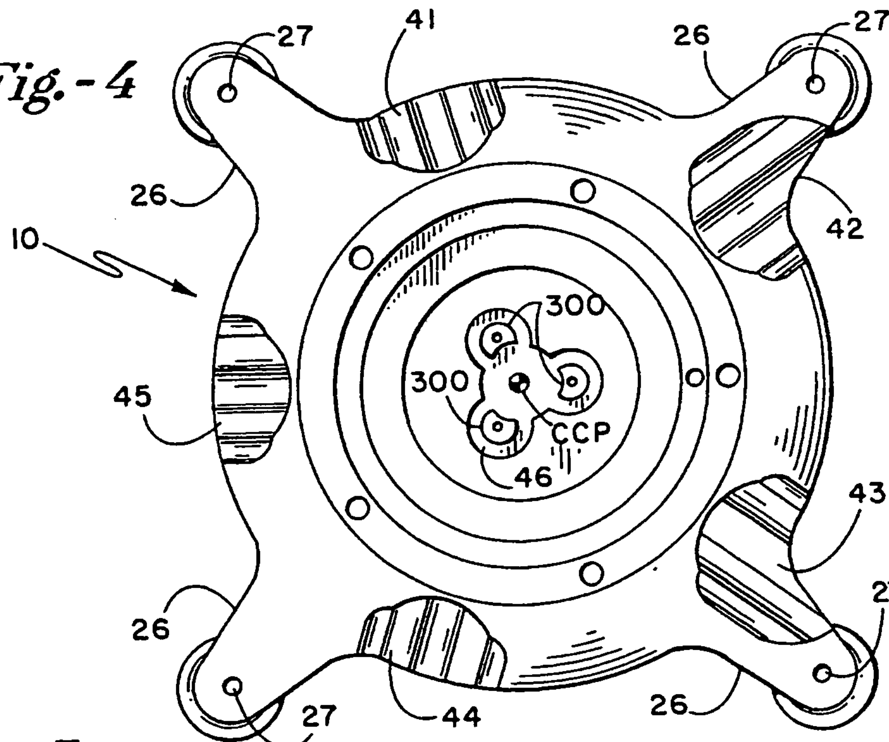

Fig.-5

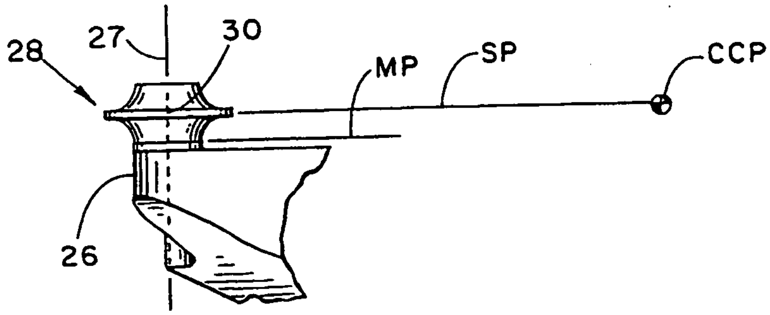

Fig.-6

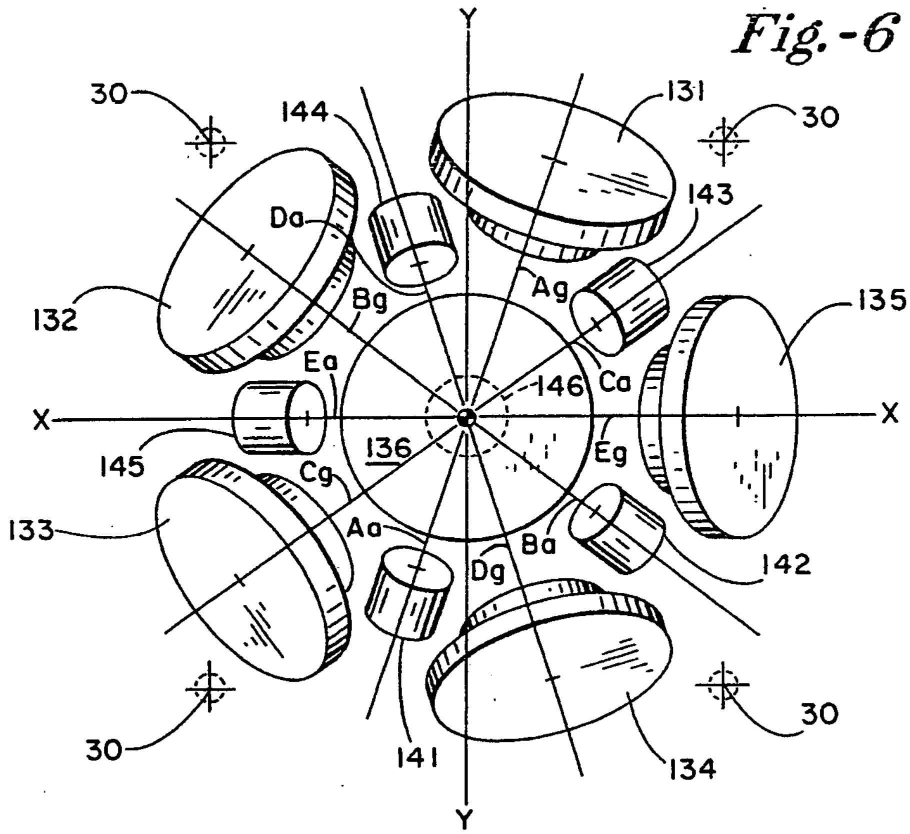
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Fig.-7

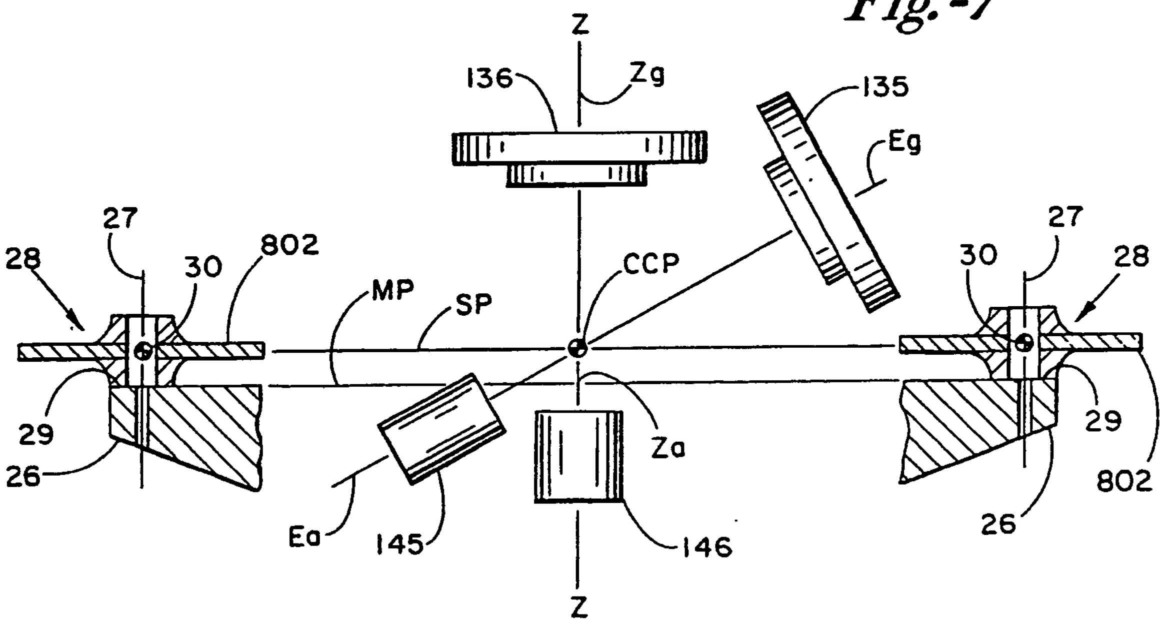
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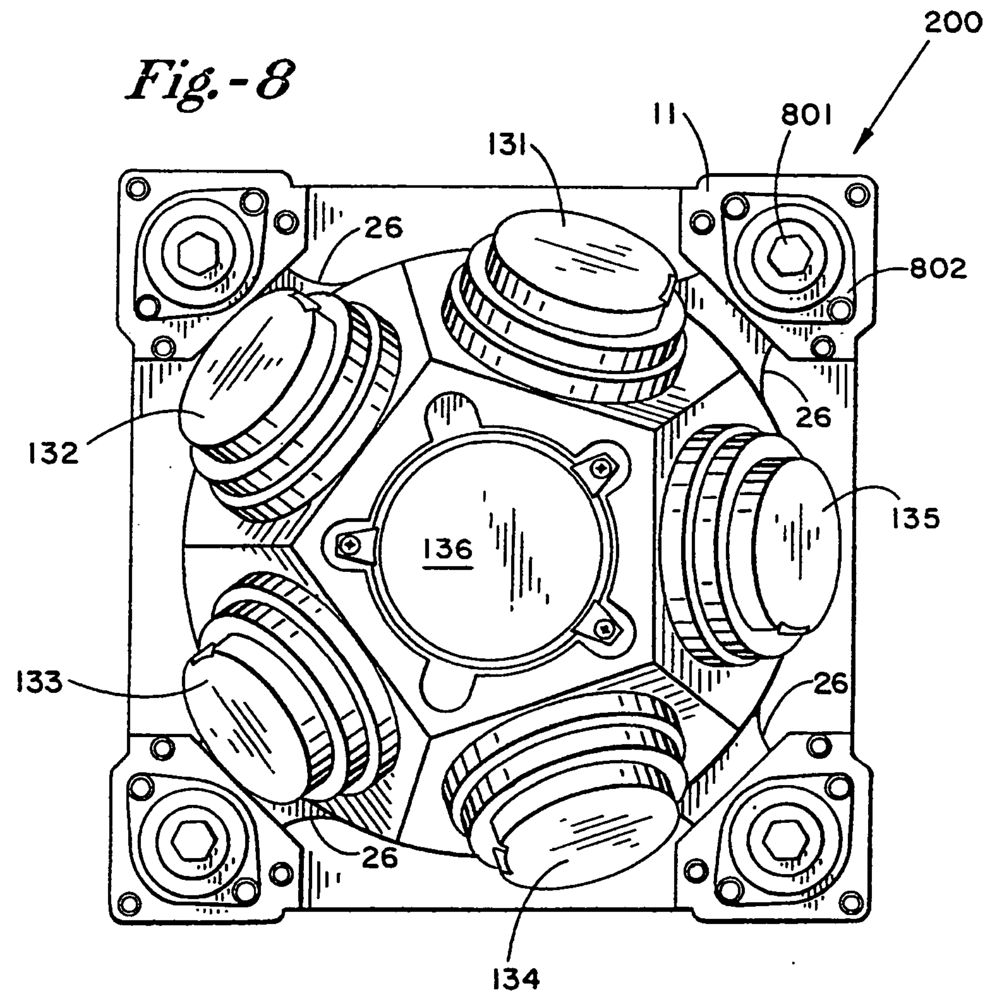
Fig.-8



INTERNATIONAL SEARCH REPORT

International Application No. PCT/US89/02221

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

U.S. Cl. 33/321, 73/178R, 74/5.34
IPC(4): G01C 19/02

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.	33/318, 321, 322; 73/178R, 504; 74/5.34, 5/37; 244/175, 176, 177

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	Journal of Spacecrafts and Rockets, Vol. 9, no. 1, January 1972, Gilmore et al, "A Redundant Strapdown Inertial Reference Unit (SIRU)" pages 39-47.	1-40
Y	US,A 3,269,179 (ANDERSON) 30 August 1966 See the entire document.	2, 4-6, 18, 19, 21-26, 30, 33, 35-40
Y	US,A 4,675,820 (SMITH) 23 June 1987 See Fig. 1.	20, 27, 34
A	US,A 3,403,874 (BOSKOVICH) 1 October 1968	1-40
A	US,A 3,463,909 (WEISS) 26 August 1969	1-40
A	US,A 3,489,004 (BARNHILL) 13 January 1970	1-40
A	US,A 4,020,702 (EPSTEIN) 3 May 1977	1-40
A	US,A 4,125,017 (DHUYVETTER) 14 November 1978	1-40
A	US,A 4,179,818 (CRAIG) 25 December 1979	1-40
A	US,A 4,212,443 (DUNCAN) 15 July 1980	1-40
A	US,A 4,711,125 (MORRISON) 8 December 1987	1-40
A,P	US,A 4,795,258 (MARTIN) 3 January 1989	1-40

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
05 JULY 1989	03 AUG 1989
International Searching Authority	Signature of Authorized Officer
ISA/US	Patrick Scanlon Patrick Scanlon

International Application No. PCT/US89/02221

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A,P	US,A 4,825,716 (ROBERTS) 2 May 1989	1-40

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers , because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers ...., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

3. ☐ Claim numbers__________, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.